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Albanian possibilities on geothermal direct utilization

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ABSTRACT

The Llixha Elbasan hot springs are among the most important geothermal springs of Albania. Balneological use dates back centuries, but the first modern use started in 1937. Unfortunately this water has not been used for its energetic values yet. The temperature of the water is above 60 °C and the flow above 16 l/s, thus direct utilization is possible, in particular for space heating. Three-dimensional temperature field calculations and engineering calculations on a heating system with heat exchangers are presented here. The results show that the water temperature is expected to be stable and considerably higher temperature is expected through deep well drilling. Geothermal water of Llixha hot springs fulfils all requirements needed for a district heating system in the region. The University's Campus of Tirana is composed of 29 buildings, which are partially heated through a coal heater. The installed capacity is 2558 kW while the coal consumption is about 920 kg/h. The University's Campus of Tirana is one of the most important areas and with the highest density of population in Tirana, so it is the best area to show the heat exchanger efficiency. The economical analyses prove that the borehole heat exchangers are more convenient than the coal heating systems.

Contents

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1. Introduction

Albania is a small country of only 28 787 km^2 surface area and around 4 500 000 inhabitants, situated in the southwest part of the Balkan Peninsula. Like the other Balkan countries, Albania is located next to the subduction boundary between the African plate and the Euro-Asiatic plate. This setting makes the presence of geothermal resources possible. Surface manifestations of geothermal resources are found throughout Albania, ranging from the region of Peshkopia in the northeast, where hot springs with water temperature of about 43 °C and inflow above 14 l/s are found, through the central part of the country with different sources (including the springs of Llixha-Elbasan) with temperatures above 66 °C, to the Peri-Adriatic depression (see Fig. 1) with a number of wells (drilled for oil and gas research) producing water with temperatures around 40 °C at variable yields. The thermal waters in Albania are only used for balneology. This form of use dates back to early in history, or to the time of the Roman Empire (i.e. the Sarandaporo's thermal baths). So far, the geothermal resources have not been utilized for other purposes, such as space heating. Estimated temperature measurements based on different geothermometers indicates that the temperature of the waters in the formation of the Llixha reservoir may be above 220 °C. The reservoir is believed to be in the depth interval of 4500–5000 m. Tirana's geothermal heat sources are:

- Underground waters of the Tirana quaternary depression;
- Underground waters of the tortonian's sandstones;
- Heat of the peri-superficial quaternary or tortonian layers;
- Limestone's and dolomites saturated with artesian waters.

The following is addressed in the material:

- The general geological conditions in the areas;
- A review of the theoretical basis of heat transfer;
- Finite-volume modeling of the whole geothermal system down to 5000 m depth, incorporating both thermal convection and conduction, based on a simple boundary conceptual model;
- House heating calculations;
- Borehole heat exchangers calculations;
- Economical analyses.

All this aims at demonstrating that the thermal water flowing from the Llixha springs is usable for direct utilization and the borehole heat exchanger heating systems are economically feasible, despite their elevated preliminary cost. This utilization would mitigate the electricity supply to the region, help improve living conditions for the local community and protect the environment of the region.

2. Geological background of the Llixha-Elbasan and Tirana region

2.1. The geological structure of Llixha region

The Llixha region is situated southwest of Elbasan. The region is well known for its thermal springs, appreciated since ancient times for their curative properties. A geological map of the region and a representative cross-section (I-I) are presented in Figs. 2 and 3.

The region under study is south of Shkumbini river valley. The surface relief increases rapidly up to intermediate elevation (300–500 m). In the western part of the region, a system of hills declines gradually in the Cërriku field. The region has a rich hydro system of small streams and many underground water-systems. The flow rate for the underground waters varies from 100 to 200 l/h in Thanë up to 5000 l/h in Tregan. Generally, the formations are composed of flysch with a diverse and chaotic morphology. This is an inhabited area, with small villages clustered around the thermal waters no more than 2–3 km from each other [1]. The region lies between two tectonic regions; the transversal Vlorë-Elbasan-Dibër and the longitudinal Leskovik-Drini river bay. Both of these connect the lower part in connection with the northern and western part of the country. In the context of Albanian tectonics, the region represents the western part of the Kruja tectonic zone. The formation represents the Llixha synclinal structure limited by the anticline structures of Elbasan-Valeshit in the east and Papri in the west. The Elbasan-Valeshi structure rises at the surface through the calcareous formation of Creta-Paleogenit, while in Papri the calcareous formations are at greater depth. The orientation of these structures is SW–NE as is the rest of the Albanides structure [2]. The formations in the region are mainly composed of flysch (three Oligocene and lower Miocene (less molasses) sections) while calcareous formations with limited surface area are mainly composed of olystolit, through the over lined terygen rocks. The biggest part is composed of lower Oligocene ($Pg_3{}^1$) rocks, consisting of 6 lithological units as shown in Fig. 2 [1]. The lowest part of the formation is composed of thinner flysch units intercalated by clays and sandstone, while the upper part is composed of thicker flysch with conglomerates. The lithology of the middle and upper Oligocene formation is mainly flysch with differently shaped packs. Interesting is the lithological evidence of the upper packs of the middle Oligocene where among the flysches are located with lengths up to 100 m. They are organized in a chain, preserving the general orientation of the other strata. Together with the conglomerate sandstone formation they form a chain alternating in relief. The lithology of the lower Miocene (Acquitan-Burdigalian) deposits is characterized by Margoles alternating with the clays-sandstones as well as the presence of sandstone-conglomerates.

The Llixha syncline represents a depressed structure with eastern asymmetry filled in the central part with terygen, flysch and molasses deposits. The eastern part is distinguished by an easterly drop. The tectonics puts the upper deposits in contact with the lower flysch Oligocene formation and has made the surface intrusion of the Eastern anticline calcareous formations possible. This tectonic layout is regional and includes the Western anticline chain of the Kruja tectonic zone [3].

The Llixha system comprises a reservoir which feeds the southern part of the Shkumbini River. The main hydrological characteristic of the region is the presence of several hot springs. Their position is related to the Kruja geothermal zone and they are connected with the calcareous olystolits of the upper Oligocene conglomerate-sandstones. The temperature of the hot springs varies, and ranges from 50 to 68 °C while flow rates vary from one spring to another, without any seasonal characteristics.

2.2. The geological structure of Tirana

Tirana aquifer is related with the syncline deposits of Tirana, whose morphology represents a depression of 10–12 km of width and 70–80 km of length, Fig. 4 (Geological map of Albania, 1984). The aquifer is composed of flysch, gravels, sandstones, alevrites and quaternary clays. Well yield in this region varies between 7 and 10 l/s, while for the Tortonians molasses which are composed of sandstone, clays and alevrites the thickness is 60–150 m while the well yield is about 3–4 l/s.

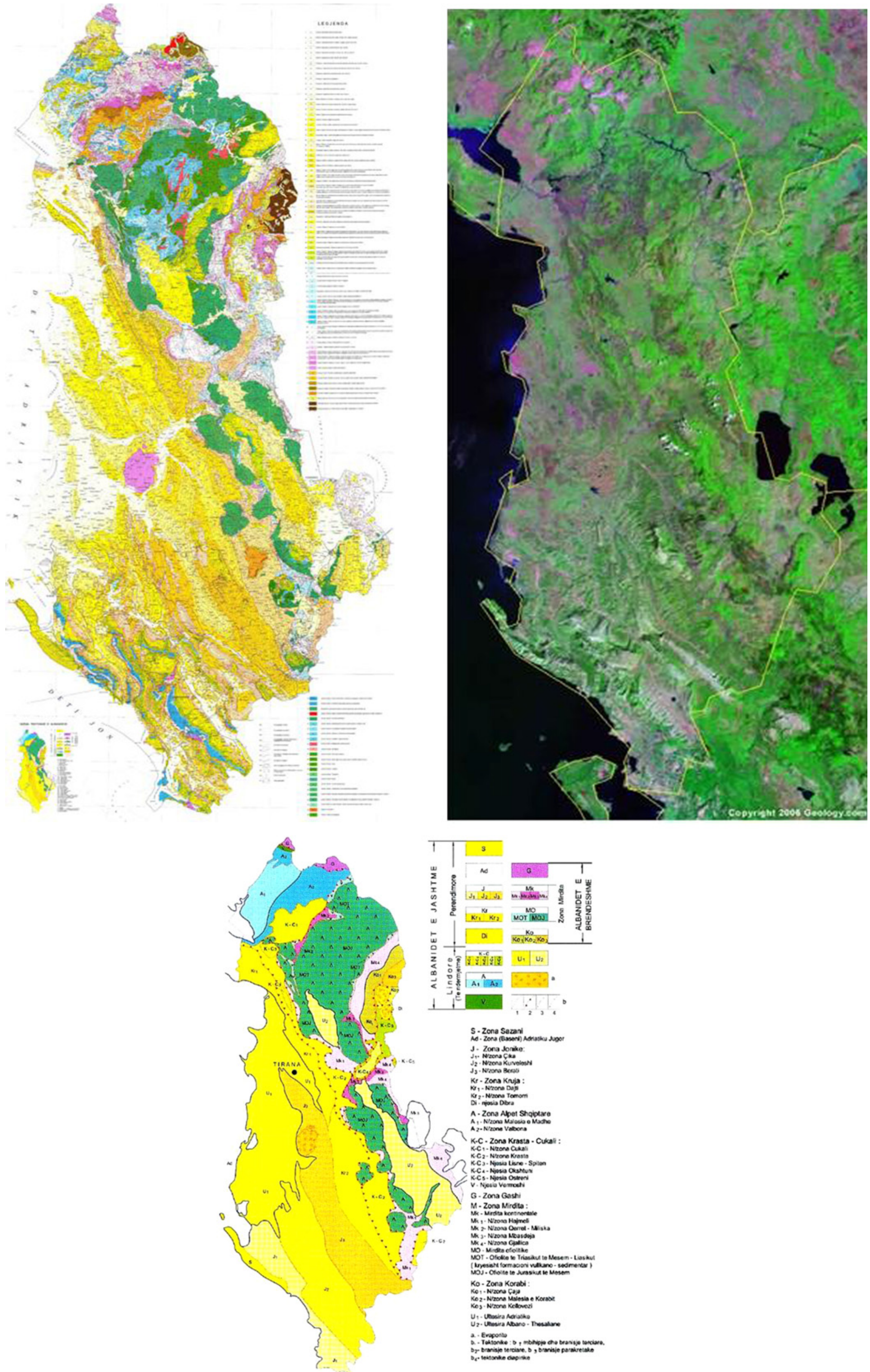

Fig. 1. Map of Albania.

3. Heat transfer theory

3.1. The differential equation for heat transfer

This equation is a mathematical expression of the first law of thermodynamics, the energy preservation low. The heat increase of an elementary volume ΔV is equal to the thermal energy which crosses the surface S. A solid medium is considered, which is not generating any energy (so the energy is only flowing through a surface S). The temperature T at a point $P(x, y, z)$ will be a continuous function of the position and time. For a homogenous solid medium, in which the thermal volume heat capacity is independent

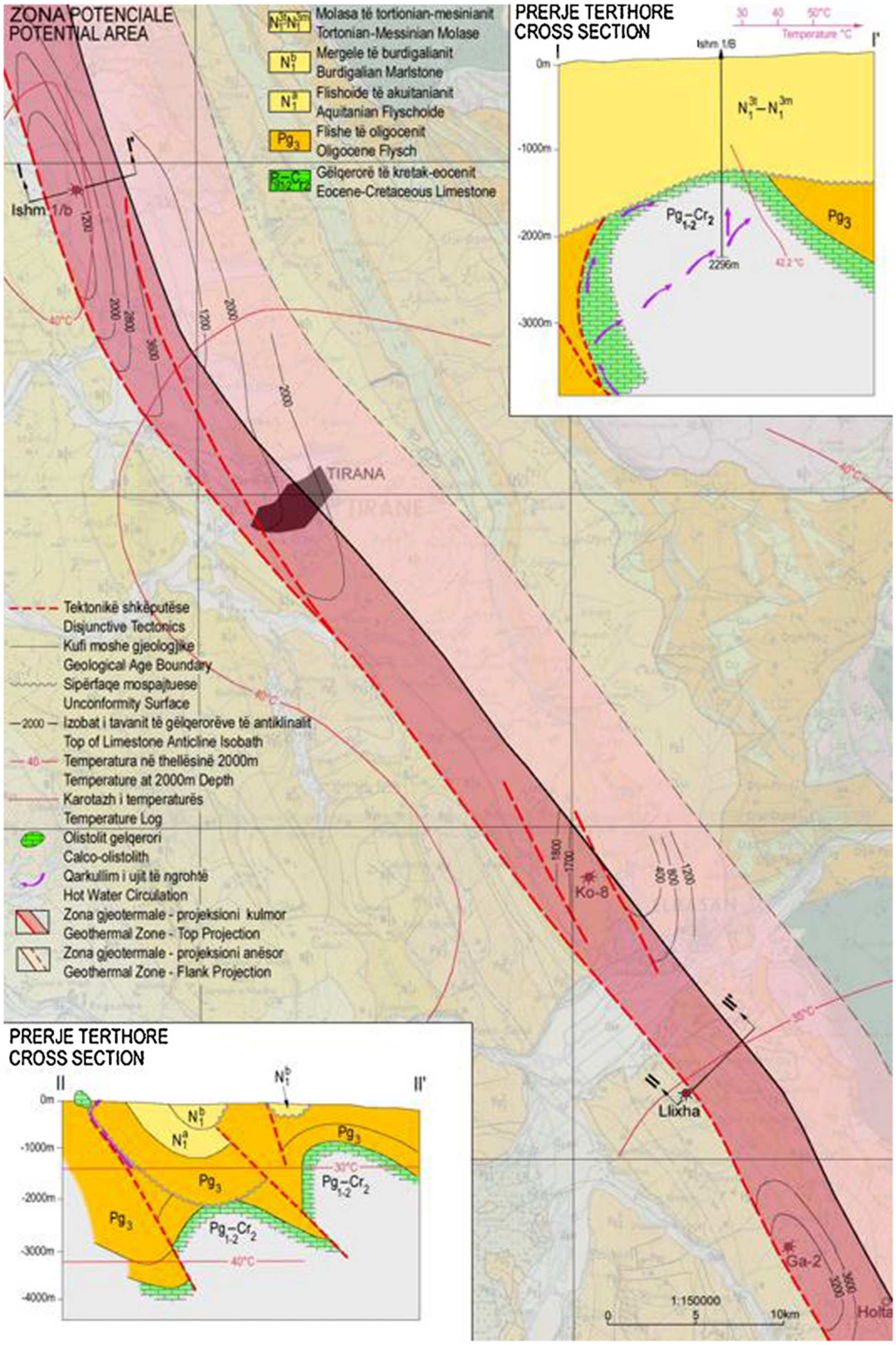

Fig. 2. Geological map of the Llixha region.

of temperature, the equation is [4]:

$$\nabla^2 T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{a}\frac{\partial T}{\partial t} \quad (1)$$

with a thermal diffusivity of the solid medium.

In polar coordinates: $x = r\cos\alpha$; $y = r\sin\alpha$, hence:

$$\nabla^2 T = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{a}\frac{\partial T}{\partial t} \quad (2)$$

Let us assume that in point $P(x, y, z)$ the energy input per unit of time and unit of volume is $A(x, y, z, t)$, then Eq. (2) is rewritten as:

$$\nabla^2 T + \frac{A(x, y, z, t)}{\lambda} = \frac{1}{a}\frac{\partial T}{\partial t} \quad (3)$$

If thermal conductivity depends on position and temperature the equation can be written as:

$$\rho C\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) + A \quad (4)$$

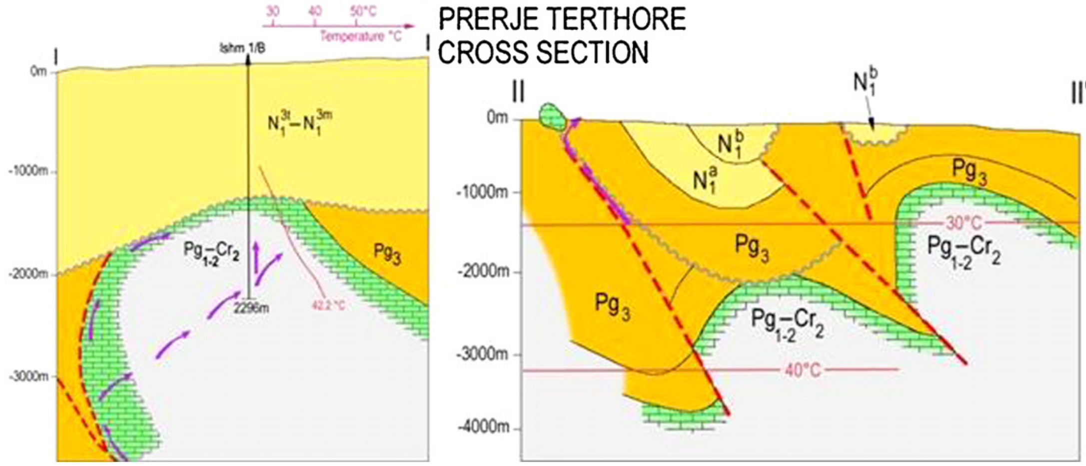

Fig. 3. Geological cross-section through the area (I-I in Fig. 2).

Its solutions are often relatively simple and can be found for different functional forms of $\lambda(x, y, z)$. If the thermal properties are temperature dependent the equation is non-linear and numerical methods can be used for its solution.

3.1.1. The basics hypothesis

Let us describe mathematically the heat exchange process between flowing fluids in a wellbore with appropriate boundary formations. Let us assume:

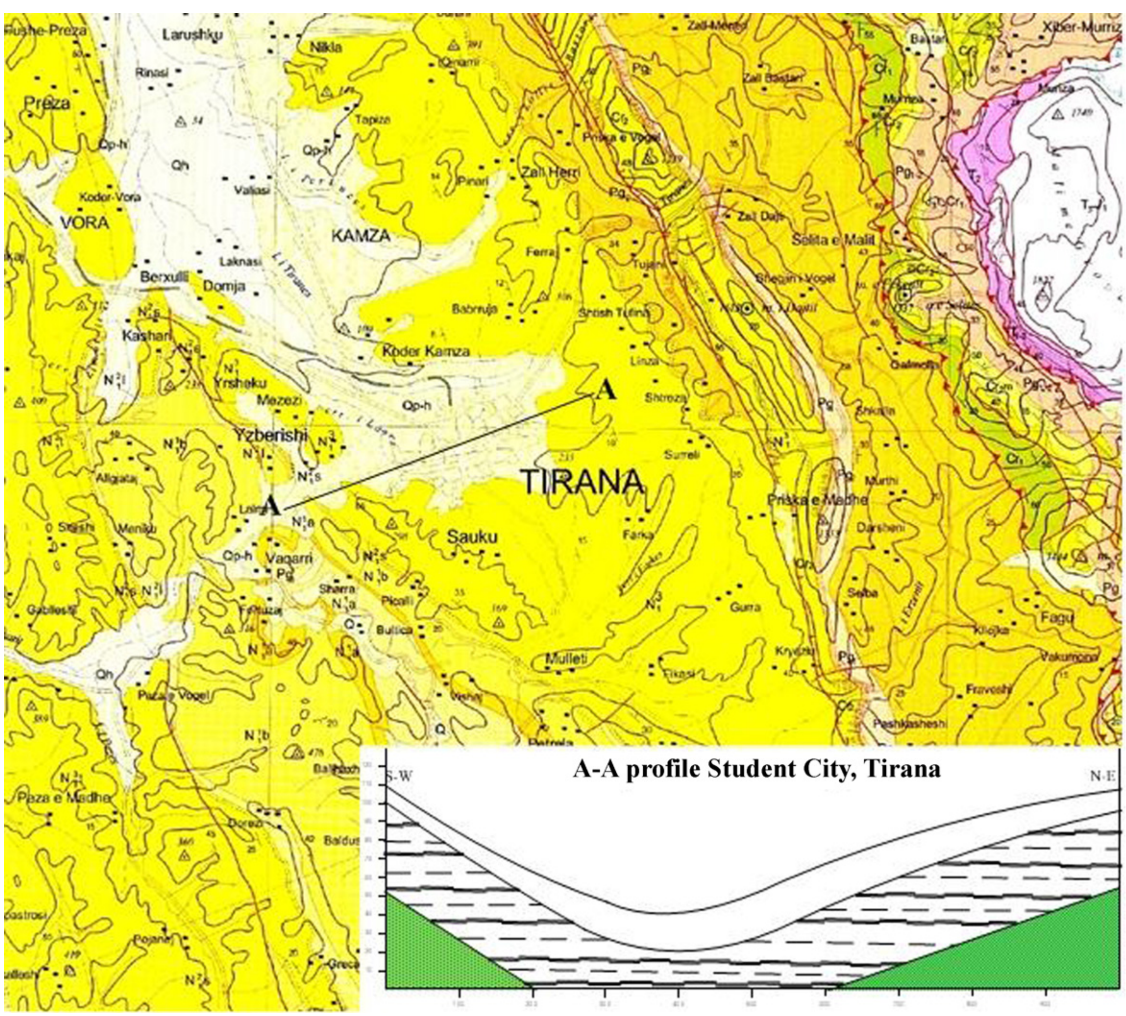

Fig. 4. Geological map of Tirana aquifer.

- The formation is homogenous and isotropic;
- The flow is in axial direction only;
- The heat flow is only by conduction;
- There is no radial temperature gradient in the wellbore;
- In the boundary zone of the wellbore the formation temperature is a known function of depth;
- The thermal properties of the fluid and formation are constant;
- The radial temperature in wellbore is constant;
- The yield from the wells is constant;
- The flow in wellbore is vertical (1D);
- The vertical heat conduction – is much less than the horizontal one, i.e. negligible.

3.2. Initial and boundary conditions

In order to solve the thermal diffusion equation let us assume that the formation temperature is function of the position (x, y, z) and time (t) [4]. In addition initial and boundary conditions must be specified. A specific moment of time is chosen as the origin of the time coordinate. At that time the temperature distribution is:

$$T(x, y, z, t=0) = f(x, y, z) \quad \text{or} \quad T(r, \theta, z, t=0) = f(r, \theta, z) \tag{5}$$

If the radials symmetric case of a flowing wellbore is considered, as an example. After a certain production time the well is shut down. To determine the temperature distribution in the wellbore during the shutdown time, the end of production is considered as the origin of the time coordinate. In this case the temperature $f(r, z)$ must be known, i.e. the initial conditions. To specify the temperature field of a medium the boundary conditions must also be known beforehand. Different kinds of boundary conditions can be specified:

- Surface temperature is known. It can be constant or function of position and time, $T = f(x, y, z, t)$.
- The amount of energy flowing through the surface is known:

$$q_s(x, y, z, t) = -\lambda \frac{\partial T}{\partial n} \quad \left\{ \frac{\partial}{\partial n} = \text{the derivation perpendicular to the surface} \right\} \tag{6}$$

- Linear surface heat flow. In such a case the amount of energy transmitted through a given surface is proportional with the temperature difference between the surfaces and the surroundings.

$$q_s = \alpha(T_s - T_0) \tag{7}$$

where T_s is the surface temperature; T_0 is the surrounding temperature; α is the heat transfer coefficient, and

$$\lim_{\alpha\to\infty} T_s = T_0 \tag{8}$$

- The connecting surface between two media with conductivities λ_1 and λ_2, respectively. If T_1 and T_2 are the temperatures of the media, then

$$T_1|_s = T_2|_s; \quad -\lambda_1 \frac{\partial T_1}{\partial n}|_s = -\lambda_2 \frac{\partial T_2}{\partial n}|_s \tag{9}$$

3.3. Temperature field modeling

In order to create a physical model to enable the stable state of heat flow through a formation to be studied, the analogy principle may be used. Let us assume that n dimensionless parameters $I_1,\ldots,I_n$ describe the heat conditions in the formation and surroundings. In such a case, the model results should be expressed as n dimensionless parameters $I'_1, \ldots, I'_n$. The conditions that must be fulfilled in order to use the model in a real reservoir are $I_1 = I'_1, \ldots, I_1 = I'_n$. For stable heat transmission, the analogy with the electrostatic field can be used. For the 2D case and with the thermal conductivity $\lambda = \lambda(x, y)$, the boundary conditions are:

$$T(z_1, x) = T_1; \quad T(z_2, x) = T_2; \quad -l \le x \le l; \quad \frac{\partial T(z, x)}{\partial x}|_{-l} = \frac{\partial T(z, x)}{\partial x}|_l = 0 \tag{10}$$

In Table 1, a summary of the analogies between hydrodynamic, heat transfer, electrostatic and electricity transmissions fields is presented. As we can see from Table 1, the temperature change ΔT is analogous with the potential difference ΔU. Assuming the length unit, l_s, the dimensionless coordinates are:

$$x' = \frac{x}{l_s}; \quad z' = \frac{z}{l_s}; \quad z'_1 = \frac{z_1}{l_s}; \quad z'_2 = \frac{z_2}{l_s}; \quad l' = \frac{l}{l_s} \tag{11}$$

The relationship $\lambda = \lambda(x, z)$ is analogous with $\rho = \rho(x, z)$. A particular care should be used in unstable field modeling. Considering the hydrodynamics analogy with the thermal one, in particular the transitory flows of an incompressible fluid through a porous medium, the main characteristics of this regime are the high values of the hydraulic diffusivity [2]:

$$\eta = \frac{k}{\phi \mu c_t} \tag{12}$$

Its thermal field analogue is the thermal diffusion coefficient (a). The analogies principle can only be used in the case when the dimensionless times are equal. In thermal field modeling, the fact that the temperature is not affected by surface topography and groundwater flow is very important. To determine the boundary conditions temperature maps at depth are widely used [5].

3.4. The unstable temperature field

Before starting investment in a geothermal project, the stability of the temperature field involved, in space and time, needs to be confirmed as well as the projects overall sustainability. The methods that can be used to answer such questions are numerous, but here we will apply the finite element method [6]. Considering the differential equation:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) + q(x, y, z) - c\frac{\partial T}{\partial t} = 0 \tag{13}$$

The functional of this equation is [6]:

$$X = X_v + X_r = \int\int\int_{\Omega} \left[\frac{k_x}{2}\left(\frac{\partial T}{\partial x}\right)^2 + \frac{k_y}{2}\left(\frac{\partial T}{\partial y}\right)^2 + \frac{k_z}{2}\left(\frac{\partial T}{\partial z}\right)^2\right] \times dxdydz + \int\int\int_{\Omega}\left(q - c\frac{\partial T}{\partial t}\right) dxdydz \tag{14}$$

Let us divide this functional into two parts:

$$X_v = \int\int\int_{\Omega} \left[\frac{k_x}{2}\left(\frac{\partial T}{\partial x}\right)^2 + \frac{k_y}{2}\left(\frac{\partial T}{\partial y}\right)^2 + \frac{k_z}{2}\left(\frac{\partial T}{\partial z}\right)^2\right] dxdydz;$$
$$X_r = \int\int\int_{\Omega}\left(q - c\frac{\partial T}{\partial t}\right) dxdydz \tag{15}$$

To integrate the Eq. (14) let us assume the time interval ($t, t + \Delta t$) through into $dT/dt = C$

Table 1
The analogy between different physical fields (based on [4]).

Hydrodynamics	Heat transfer	Electrostatics	Electricity transmission
Pressure	Temperature	Electrostatic potential	Potential
P	T	Φ	U
Pressure gradient	Temperature gradient	Field vector	Potential gradient
$-\nabla P$	$-\nabla T$	$E=-\nabla\Phi$	$-\nabla U$
Permeability/viscosity k/μ	Thermal conductivity λ	Dielectric constant $\varepsilon/4\pi$	Specific resistance ρ
Velocity vector $\vec{v}=-\frac{k}{\mu}\nabla p$	Heat amount transfer $\vec{q}=-\nabla T$	Dielectric displ. $(\varepsilon/4\pi)\vec{E}=-(\varepsilon/4\pi)\nabla\Phi$	Current $\vec{I}=-\nabla U$
Isobaric surface $\rho=C$	Isothermal surface $T=C$	Surface with electrostatic potential $\Phi=C$	Surface with potential $s=C$
Impermeable layer $\frac{\partial p}{\partial n}=0$	Split surface $\frac{\partial T}{\partial n}=0$	Force line $\frac{\partial \Phi}{\partial n}=0$	Potential line $\frac{\partial U}{\partial n}=0$

T_i: temperature values in the nodes $I=1, 4$

$$\frac{\partial X}{\partial T_i}=\frac{\partial X_v}{\partial T_i}+\frac{\partial X_r}{\partial T_i};\quad T=\frac{1}{6\Delta}\left\{N_1\quad N_2\quad N_3\quad N_4\right\}\left\{\begin{matrix}T_1\\T_2\\T_3\\T_4\end{matrix}\right\}\quad \text{where}$$

$$N_i(x,y,z)=(a_i+b_ix+c_iy+d_iz);\quad i=\overline{1,4} \tag{16}$$

The partial derivates of the functional can be calculated as follows:

$$\frac{\partial X}{\partial T_i}=\left\{\begin{matrix}\frac{\partial X}{\partial T_1}\\\frac{\partial X}{\partial T_2}\\\frac{\partial X}{\partial T_3}\\\frac{\partial X}{\partial T_4}\end{matrix}\right\}=\left\{\frac{k_x}{36\Delta}\begin{vmatrix}b_1^2 & b_1b_2 & b_1b_3 & b_1b_4\\ b_2b_1 & b_2^2 & b_2b_3 & b_2b_4\\ b_3b_1 & b_3b_2 & b_3^2 & b_3b_4\\ b_4b_1 & b_4b_2 & b_4b_3 & b_4^2\end{vmatrix}+\frac{k_y}{36\Delta}\begin{vmatrix}c_1^2 & c_1c_2 & c_1c_3 & c_1c_4\\ c_2c_1 & c_2^2 & c_2c_3 & c_2c_4\\ c_3c_1 & c_3c_2 & c_3^2 & c_3c_4\\ c_4c_1 & c_4c_2 & c_4c_3 & c_4^2\end{vmatrix}+\frac{k_z}{36\Delta}\begin{vmatrix}d_1^2 & d_1d_2 & d_1d_3 & d_1d_4\\ d_2d_1 & d_2^2 & d_2d_3 & d_2d_4\\ d_3d_1 & d_3d_2 & d_3^2 & d_3d_4\\ d_4d_1 & d_4d_2 & d_4d_3 & d_4^2\end{vmatrix}\right\}\begin{vmatrix}T_1\\T_2\\T_3\\T_4\end{vmatrix}$$

$$-\begin{vmatrix}\iiint_\Omega N_1^2dxdydz & \iiint_\Omega N_1N_2dxdydz & \iiint_\Omega N_1N_3dxdydz & \iiint_\Omega N_1N_4dxdydz\\ \iiint_\Omega N_2N_1dxdydz & \iiint_\Omega N_2^2dxdydz & \iiint_\Omega N_2N_3dxdydz & \iiint_\Omega N_2N_4dxdydz\\ \iiint_\Omega N_3N_1dxdydz & \iiint_\Omega N_3N_2dxdydz & \iiint_\Omega N_3^2dxdydz & \iiint_\Omega N_3N_4dxdydz\\ \iiint_\Omega N_4N_1dxdydz & \iiint_\Omega N_4N_2dxdydz & \iiint_\Omega N_4N_3dxdydz & \iiint_\Omega N_4^2dxdydz\end{vmatrix}\begin{vmatrix}\frac{\partial T_1}{\partial t}\\\frac{\partial T_2}{\partial t}\\\frac{\partial T_3}{\partial t}\\\frac{\partial T_4}{\partial t}\end{vmatrix}-\frac{Q\Delta}{4}\begin{vmatrix}1\\1\\1\\1\end{vmatrix}=\begin{vmatrix}0\\0\\0\\0\end{vmatrix} \tag{17}$$

Let us make the following replacements:

$$\frac{k_x}{36\Delta}\begin{vmatrix}b_1^2 & b_1b_2 & b_1b_3 & b_1b_4\\ b_2b_1 & b_2^2 & b_2b_3 & b_2b_4\\ b_3b_1 & b_3b_2 & b_3^2 & b_3b_4\\ b_4b_1 & b_4b_2 & b_4b_3 & b_4^2\end{vmatrix}+\frac{k_y}{36\Delta}\begin{vmatrix}c_1^2 & c_1c_2 & c_1c_3 & c_1c_4\\ c_2c_1 & c_2^2 & c_2c_3 & c_2c_4\\ c_3c_1 & c_3c_2 & c_3^2 & c_3c_4\\ c_4c_1 & c_4c_2 & c_4c_3 & c_4^2\end{vmatrix}+\frac{k_z}{36\Delta}\begin{vmatrix}d_1^2 & d_1d_2 & d_1d_3 & d_1d_4\\ d_2d_1 & d_2^2 & d_2d_3 & d_2d_4\\ d_3d_1 & d_3d_2 & d_3^2 & d_3d_4\\ d_4d_1 & d_4d_2 & d_4d_3 & d_4^2\end{vmatrix}=[H] \tag{18}$$

$$\begin{vmatrix}\iiint_\Omega N_1^2dxdydz & \iiint_\Omega N_1N_2dxdydz & \iiint_\Omega N_1N_3dxdydz & \iiint_\Omega N_1N_4dxdydz\\ \iiint_\Omega N_2N_1dxdydz & \iiint_\Omega N_2^2dxdydz & \iiint_\Omega N_2N_3dxdydz & \iiint_\Omega N_2N_4dxdydz\\ \iiint_\Omega N_3N_1dxdydz & \iiint_\Omega N_3N_2dxdydz & \iiint_\Omega N_3^2dxdydz & \iiint_\Omega N_3N_4dxdydz\\ \iiint_\Omega N_4N_1dxdydz & \iiint_\Omega N_4N_2dxdydz & \iiint_\Omega N_4N_3dxdydz & \iiint_\Omega N_4^2dxdydz\end{vmatrix}=[P] \tag{19}$$

$$\frac{Q\Delta}{4}=[F] \tag{20}$$

where $[H]$ is the matrix of conductivity of the thermal field, $[P]$ is the matrix of instability of the thermal field, $[F]$ is the source vector.

After these replacements the definitive form of Eq. (17) becomes:

$$[H]\left|T\right|+[P]\frac{\partial T}{\partial t}-\left|F(t)\right|=0 \tag{21}$$

4. District heating system using the geothermal water

In general the geothermal water for district heating systems is taken directly from low temperature reservoirs. Another way is to use the geothermal water through the heat exchangers to heat up the fresh water. The hot water can be stored in tanks if appropriate. This water then is transmitted to the buildings and can be used for heating and as tap water. Heat flow to the buildings is controlled by the mass flow. In the following are given the basics calculations for the geothermal district heating. The main elements of the geothermal district heating are the radiators and also this use is affected by the water thermal energy, building heat loss, pipe heat loss and building energy storage. A short description for all of them is given below.

Table 2
Estimated water temperature at depth based on different geo-thermometers.

Geothermometer	Spring "Nosi" Llixha, Elbasan (°C)
Fournier	254
Truesdell	235
Na + Ka + Ca	143

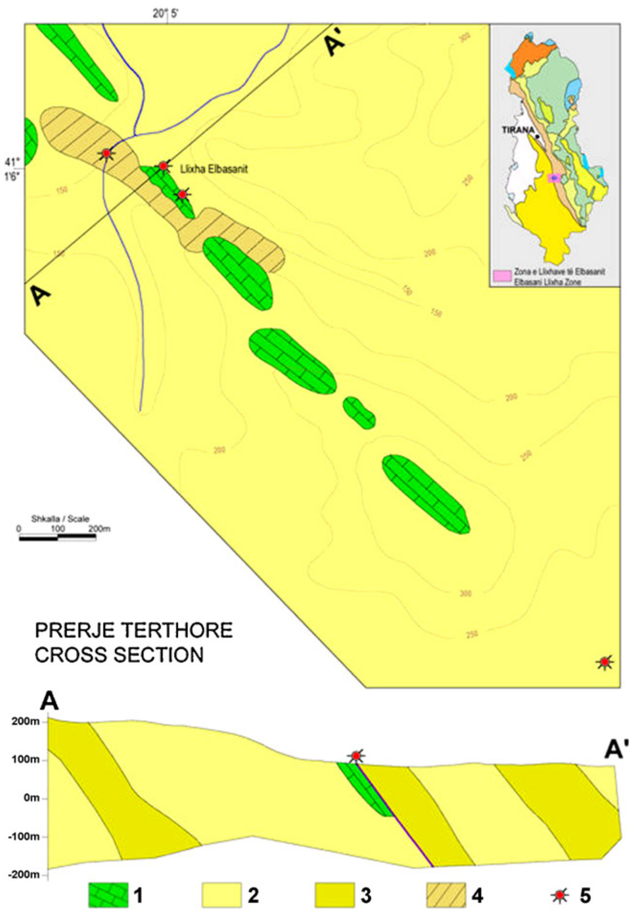

Fig. 5. Geomorphologic map of the Llixha region.

4.1. Calculation procedure for house heating systems

Radiators are the heat exchangers and they make the transfer of the heat from the geothermal water to the indoor possible.

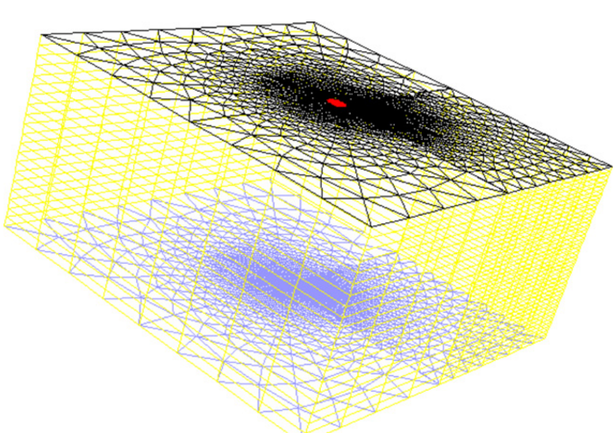

Fig. 6. The finite volume grid.

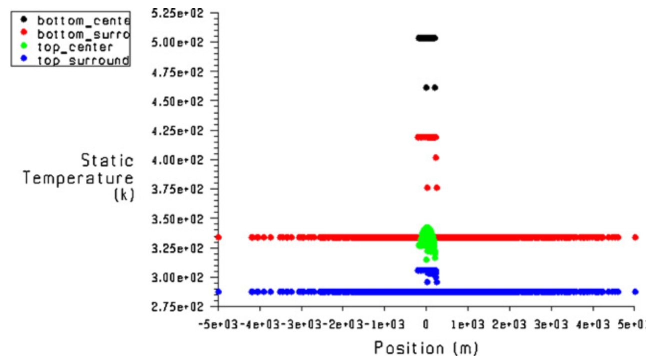

Fig. 7. The temperature magnitude.

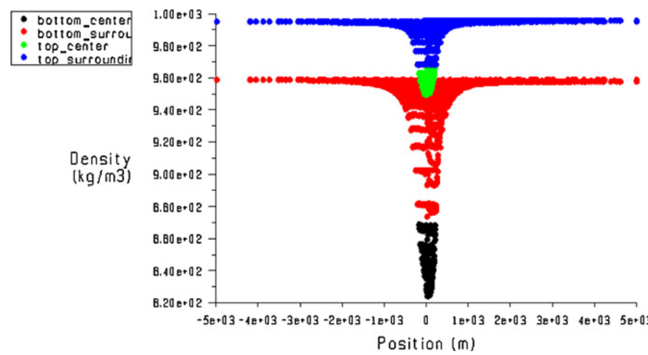

Fig. 8. The density magnitude.

The relative heat capacity of the radiator is given by the following relation:

$$\frac{Q^{rad}}{Q_0^{rad}} = \left(\frac{\Delta T_m}{\Delta T_{m0}}\right)^{4/3} \tag{22}$$

where the subscript 0 denotes the design conditions. The temperature difference ΔT_m is calculated [7]:

$$\Delta T_m = \frac{(T_s - T_i) - (T_r - T_i)}{\ln\left((T_s - T_i)/(T_r - T_i)\right)} = \frac{T_s - T_r}{\ln\left((T_s - T_i)/(T_r - T_i)\right)} \tag{23}$$

The water thermal energy which the geothermal water will give to the indoors, through the radiators is:

$$Q^{rad} = c_p m(T_s - T_r) \tag{24}$$

The relative thermal energy given by the geothermal water is [7]:

$$\frac{Q^{rad}}{Q_0^{rad}} = \frac{m(T_s - T_r)}{m_0(T_{s0} - T_{r0})} \tag{25}$$

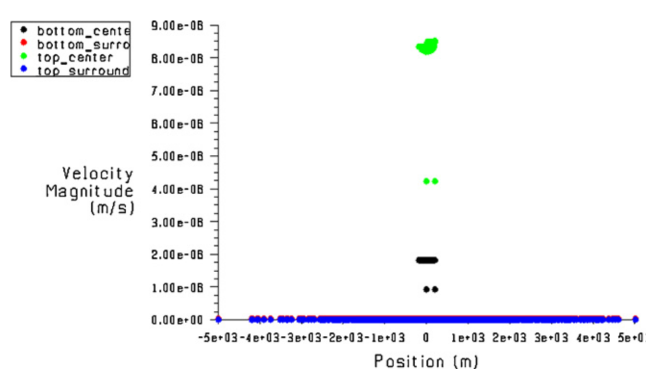

Fig. 9. The velocity magnitude.

Table 3
Thermal characteristics of the rocks.

Age	Lithology	Thermal conductivity (W/m °C)	Thermal resistance (m °C/W)
Tortonian	Sandstone	1.6	0.625
–	Clay	1.5	0.666

Table 4
Physical characteristic of the sandstones.

Layer	Filtration coefficient	Water conductivity (m/day)	Specific yields (lm/s)
Tortonian sandstone, upper part	0.08	3.2	0.038
Tortonian sandstone, lower part	0.08	5.3	0.038

The biggest part of the energy loss in such system may come from the buildings. These losses can be calculated as [7]:

$$Q_{loss} = k_l(T_i - T_0) \tag{26}$$

where building heat loss factor k_l is constant. The relative losses are [7]:

$$\frac{Q_{loss}}{Q_{loss0}} = \frac{T_i - T_0}{T_{i0} - T_{00}} \tag{27}$$

The other losses in such system are the pipe heat losses. To determine the amount of losses in the pipes it is necessary to know the pipe transmission effectiveness parameter τ. Its value [17] is given by:

$$\tau = \frac{T_s - T_g}{T_1 - T_g} = \exp\left(-\frac{U_p}{mc_p}\right) \tag{28}$$

The reference value of τ can be calculated from the reference flow conditions as follows:

$$\tau_0 = \frac{T_{s0} - T_{g0}}{T_{10} - T_{g0}} = \exp\left(-\frac{U_p}{m_0 c_p}\right) \tag{29}$$

The values of U_p and c_p are assumed to be constant in the system. By combining Eqs. (28) and (29), the transmission effectiveness can be calculated:

$$\tau = \tau_0^{m_0/m} \tag{30}$$

The supply temperature to the house can be calculated:

$$T_s = T_g + (T_1 - T_g)\tau = T_g + (T_1 - T_g)\tau_0^{m_0/m} \tag{31}$$

and the return water temperature at the pumping station is calculated:

$$T_2 = T_g + (T_r - T_g)\tau = T_g + (T_r - T_g)\tau_0^{m_0/m} \tag{32}$$

A building's heat storage (dependent on the amount of the thermo-insulation) can be very helpful for the heating system. Normally the builds are like a heat store. The building heat storage is calculated by [7]:

$$\frac{dT_i}{dt} = \frac{1}{c}Q_{net} = \frac{1}{c}(Q_{sup} - Q_{loss}) = \frac{1}{c}\left[mc_p(T_s - T_r) - k_l(T_i - T_0)\right] \tag{33}$$

5. Borehole heat exchangers

5.1. Equation for heat flow

The equation for rate of heat transfer from the fluid in the heat exchanger to the earth mass is:

$$\frac{Q}{L} = U \times \Delta T \tag{34}$$

where Q is the rate of heat exchanger (BTU/h or W) for the whole heat exchanger length; L is the length of heat exchanger (m); U is the conductance rate for heat transfer from the circulating fluid to the earth (BTU/h/°F or W/°C/m) for the operating conditions: ΔT is the difference in fluid temperature:

$$\Delta T = \frac{T_2 + T_1}{2} - T_0 \tag{35}$$

T_0 is the earth temperature (°F or °C); T_1 is the fluid entry temperature (°F or °C); T_2 is the fluid exit temperature (°F or °C).

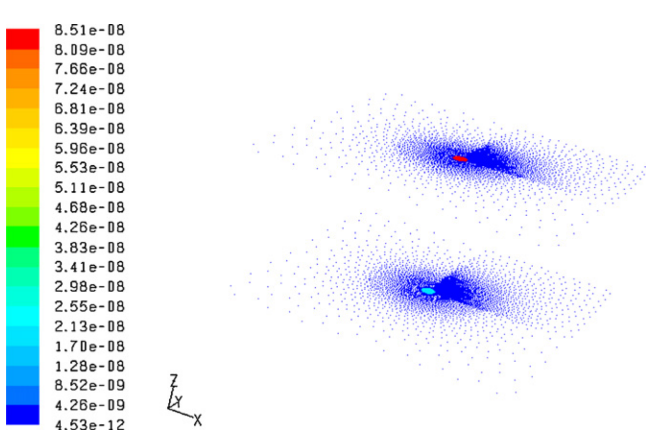

Fig. 10. The velocity vectors.

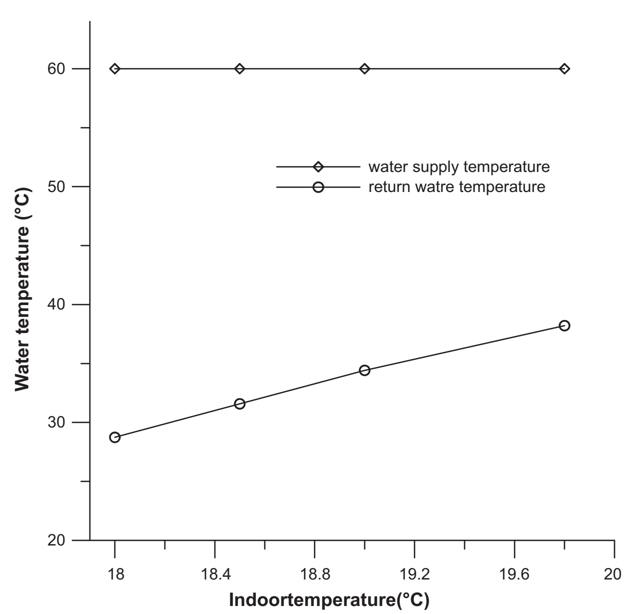

Fig. 11. Calculations for the radiators.

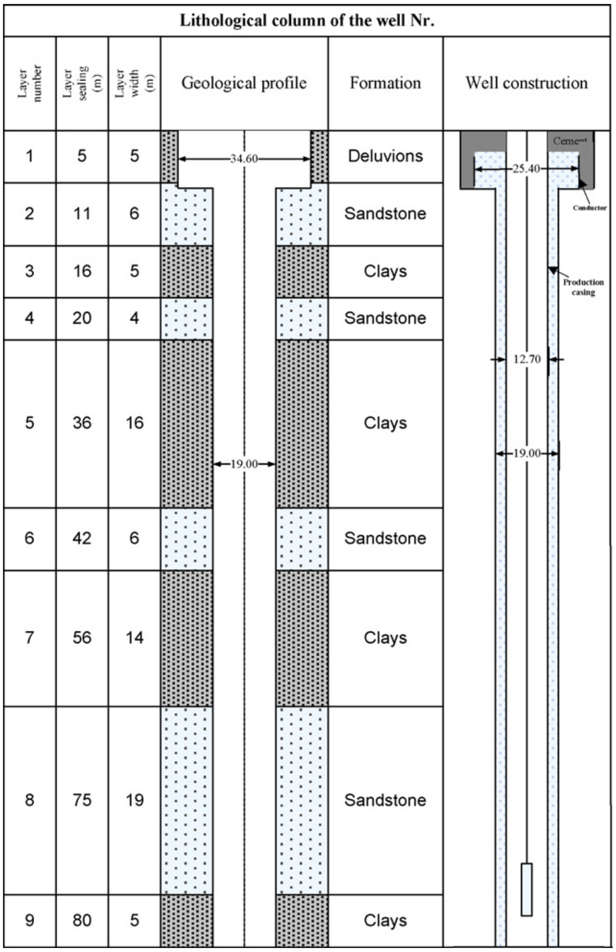

Fig. 12. Lithological column of a well drilled in Tirana.

The conductance term U for heat flow from fluid in the heat exchanger to the earth can be estimated with the conductance coefficient for composite cylinders. The impedance to heat flow is caused by the thermal resistance of the pipe wall and the soil cylinder around the casing. Fluid surface resistance films are small relative to the other terms and are encompassed in the two resistance terms. We can express U as:

$$U = \frac{2\pi}{\text{soil resistance} + \text{pipe resistance}} = \frac{2\pi}{R_s + R_p} \qquad (36)$$

6. Results of simple hot spring modeling

The six hot water springs at Llixha in the Elbasan region, have water temperature up to 65 °C and flow rate up to 23 l/s. Estimated reservoir temperature at depth associated with the hot springs, based on the chemical composition using different geothermometers, is given in Table 2.

These values show that the water is coming from great depth where the average temperature is over 200 °C. As it is shown in Fig. 5 [8], the hot springs are situated in the middle of the village. The hot water has been used only for balneology for several centuries possibly since the time of the Roman Empire. The first modern use dates back to 1937 with the building of the "Hotel Park" medical centre. The use of the water flowing from these springs can help to improve the economical effectiveness district heating in the village. The realization of such a project will allow the utilization of geothermal water as an energy resource for the first time in Albania. The purpose of the calculations presented in this chapter is to show that the water of these hot springs can be used for the district heating of the village community.

6.1. The 3-D modeling of the temperature field of Llixha, Elbasan region

A finite volume model was set up for a crustal volume with an area of 10 km × 10 km and 5 km thickness to model the temperature, density and fluid velocity distribution in the Llixha region. The grid is shown in Fig. 6. Here it is assumed that the medium is homogeneous and isotropic and that $k_x = k_y = k_z = 2$ W/m K [9]. We also know that $Q = 20$ l/s (corresponding to $m_i = Q/6 = 3.3$ l/s or 3.224 kg/s for each of the hot springs), $c_p = 4180$ J/kg °C [8]. The temperature at depth in the formation is set at 221 °C while the temperature of the water at the surface is in the range 60–65 °C. The temperature gradient of the surroundings is assumed 12 °C/km. The modeling software FLUENT is used to solve the problem, it provides calculation results for temperature, density and velocity for the volume modeled. In the model water flows with a velocity of 1.25×10^{-7} m/s. The results for temperature, density and velocity, as well as velocity vectors, are shown in Figs. 7–10.

7. Basic district heating design

7.1. Calculation for the radiators

The steps used to calculate the radiator parameters are given in Section 4. In these calculations, it was assumed that the supply temperature of the water is 60 °C, the reference temperature 65 °C, and the ground temperature 6 °C. The calculations were done for 4 different scenarios: The indoor temperature is assumed to change at the range of 18–20 °C, the outdoor temperature in the range of −10 to −4 °C, the return water temperature in the range of 33–40 °C, the reference inflow in the range of 3.93–7 kg/s, the reference system inflow 18–24 kg/s. Based on these data, the relative heating of the radiators was calculated as 0.83–0.92, the relative heating of the building as 0.87–0.88, and the transmissivity coefficient $\tau = 0.94$. To be within these parameters, it is sufficient that the supply water temperature be 60 °C, and the inflow of the system 16–27 kg/s. Thus the parameters for the Llixha thermal springs satisfy all these demands. Fig. 11 shows the results of the calculations for the radiators supply and return water temperatures vs. indoor temperature.

7.2. Borehole heat exchanger calculations

Heat exchanger length is calculated through Eq. (34). The thermal characteristics of the rocks drilled by the well of Fig. 12 are given in Table 3, while the physical characteristics of Tirana tortonian sandstones are given in Table 4.

For this well is known:

- Dynamic level 100 m;
- Static level 50 m;
- Level falls 40 m;
- Pump depth 108 m;
- Average yield 1 l/s;
- pH 7.5–8;
- Water temperature 13–15 °C;
- General strength 10–15 °Gj;
- Mineralization 250–350 mg/l;
- Formula HCO_3–Ca–Mg;

The thermal resistance for the formations R_p drilled by the well is calculated as follows:

$$R_p = \frac{(40 \times 0.666 + 34 \times 0.625)}{40 + 35} = 0.647 \frac{\text{m} \times^\circ \text{C}}{\text{W}}$$

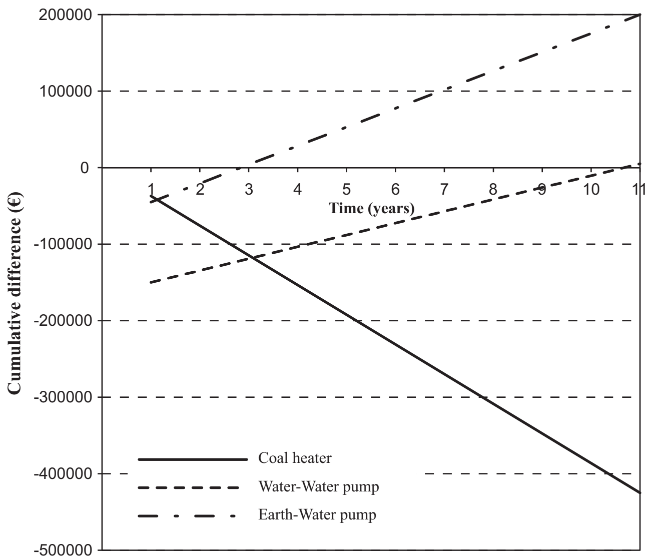

Fig. 13. The economical analyses of three different systems.

The conductance rate U is calculated:

$$U = \frac{2\pi}{R_p} = \frac{2\pi}{0.647} = 9.711 \frac{\mathrm{W}}{\mathrm{m} \times^{\circ} \mathrm{C}}$$

According to the measurements, the earth temperature in 100 m depth in Tirana is $T_0 = 18\,^{\circ}\mathrm{C}$. The fluid exit temperature is $3.5\,^{\circ}\mathrm{C}$ lower than the fluid entry temperature. The difference temperature of the system is calculated:

$$\Delta T = T_0 - \frac{T_1 + T_2}{2} = 6.75\,^{\circ}\mathrm{C}$$

For these parameters the heat exchangers, for the installed capacity of 100 kW result:

$$L = \frac{Q}{U \times \Delta T} = \frac{100 \times 10^3}{9.711 \times 6.75} = 1525\,\mathrm{m}$$

So the problem is solved through drilling process of 15 wells 100 m depth each. The economic analyses (profit-expenditure) of three systems: Water–Water geothermal pumps, Earth–Water geothermal pump and the existing coal heater are presented in Fig. 13. So it can be clearly seen that the maximal profit is for the Water–Water system than for the Earth–Water and finally for the coal heater. The payback period for the geothermal heating pumps varies from 2.8 up to 10.75 years.

8. Conclusions

Based on the calculations presented in this report the following can be concluded regarding utilization of the hot springs of the Llixha-Elbasan hot-spring area in Albania:

- The water temperature is expected to be stable in the future;
- The geothermal water from the Llixha hot springs fulfils all requirements for district heating's in the region;
- Considerably higher temperature expected through further well drilling;
- Albanian geothermal regime allows different scale borehole heat exchangers applications;
- Demographic and geological features of the student's city allow, and furthermore are feasible the borehole heat exchanger's utilization.

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